This lecture is being recorded

18-452/18-750
Wireless Networks and Applications
Lecture 18: 5G

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Spring Semester 2021
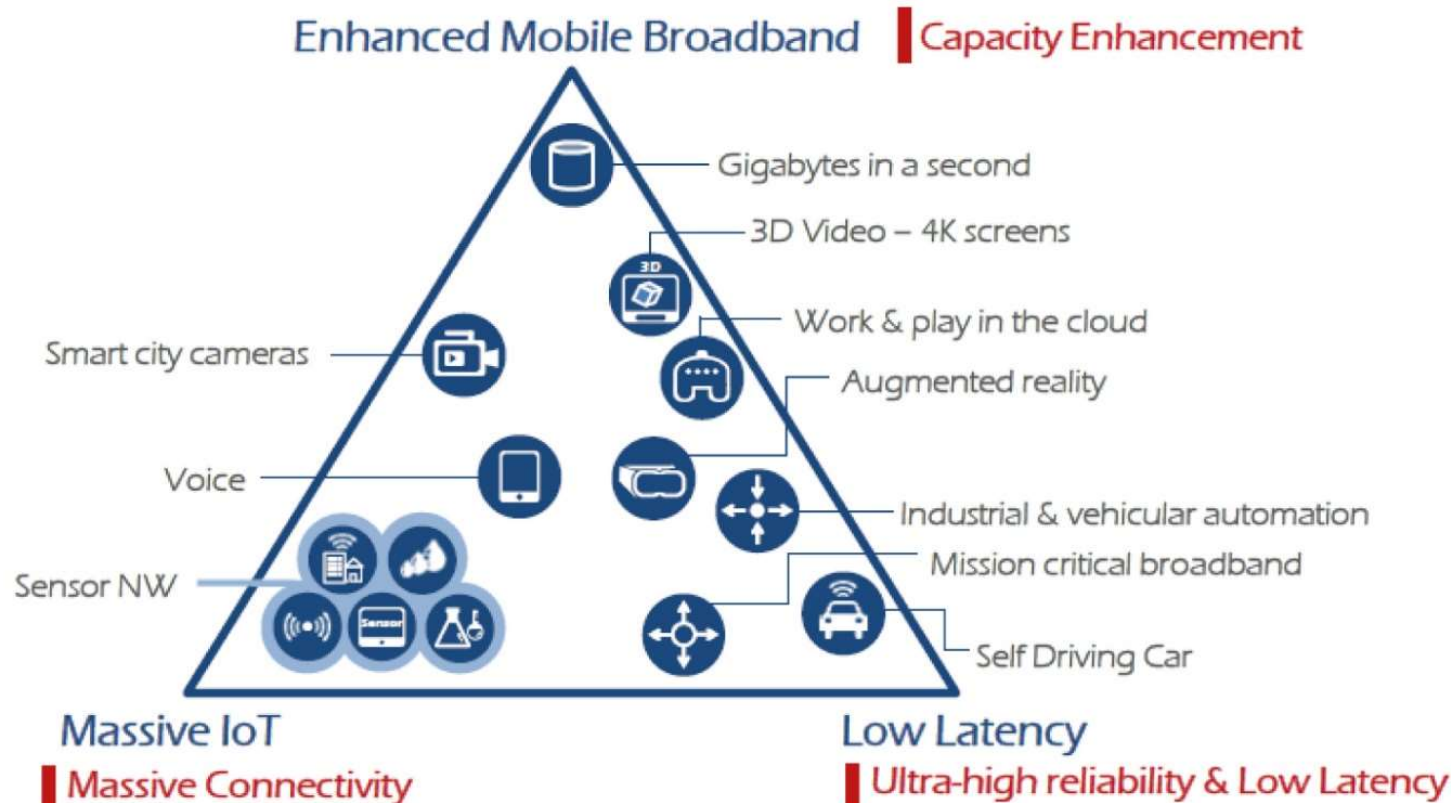
http://www.cs.cmu.edu/~prs/wirelessS21/

Overview 5G

- **Goals and Motivation**
- **Architecture**
- **Managing heterogeneity**
- **Virtualization and cloud technology**
- **Cloud-RAN**
- **5G campus networks**

5G Vision ITU
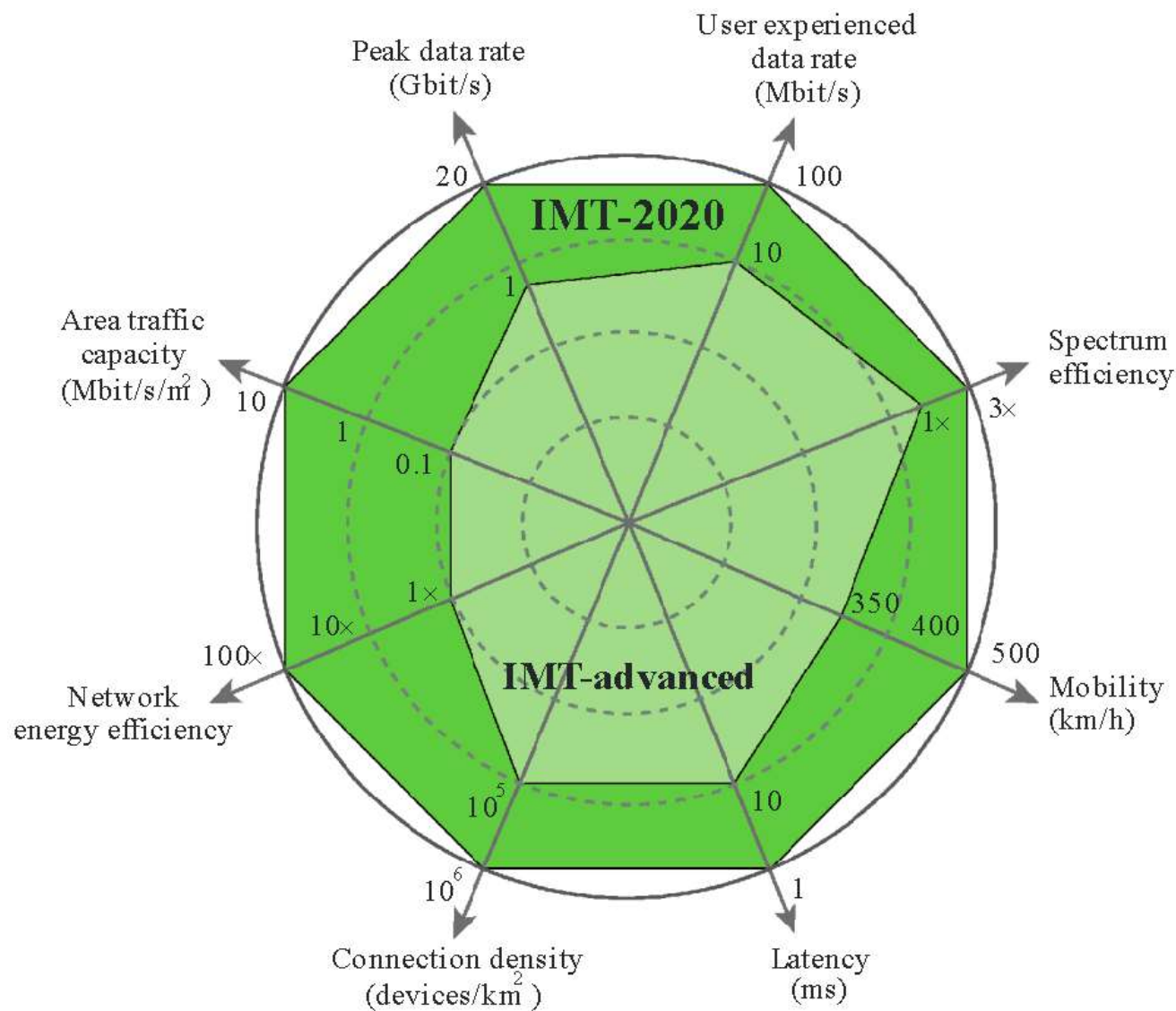# International Mobile Telecommunications

Faster 4G

Growing application domains

(Source: ETRI graphic, from ITU-R IMT 2020 requirements)

https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf
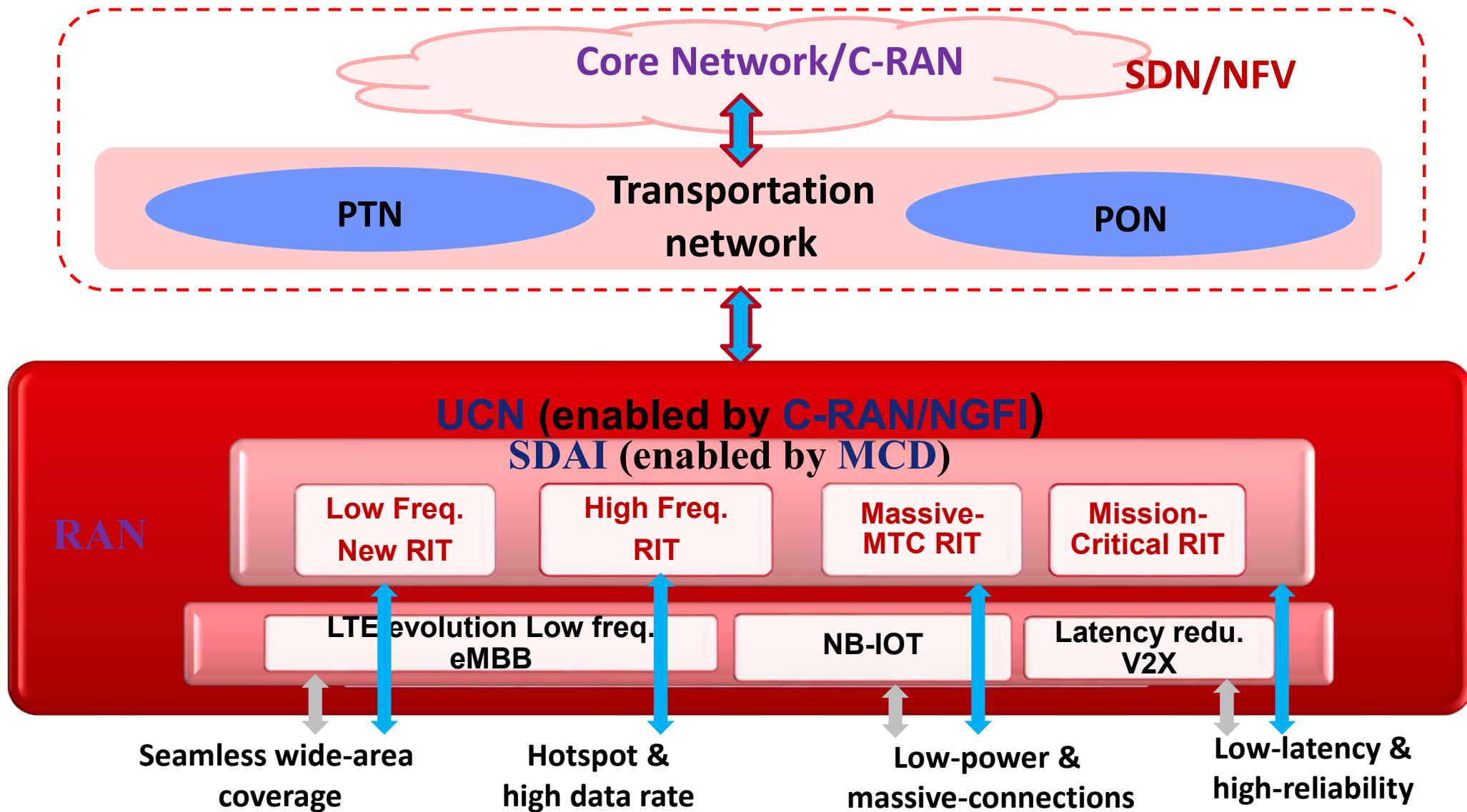
Performance Goals ITU

5G technology
More of the same?

- **Goal is 10+ fold increase in bandwidth over 4G**
  - » **Combination of more spectrum and more aggressive use of 4G technologies**

- **Very aggressive use of MIMO**
  - » **Tens to hundred antennas**
  - » **Very fine grain beamforming and MU-MIMO**

- **More spectrum: use of millimeter bands**
  - » **Low band: below 2Ghz, e.g., 660-850 MHz**
  - » **Mid band: below 6 GHz, new bands, e.g., 2.5-3.7 GHz**
    - – **https://www.cnn.com/2021/03/14/tech/5g-spectrum-auction-att-verizon-tmobile/index.html**
  - » **High band: mmWave, over 26 GHz, e.g., 25-39 GHz**
    - – **New bands - challenging but a lot of spectrum available**

Is That Enough?

- **Scaling up existing solutions attacks bandwidth challenges, but what about …**
- **Dealing with heterogeneity**
  - » **Widely different traffic loads**
  - » **Use of very different parts of the spectrum**
- **Dealing with increased complexity**
  - » **Multiple traffic classes, signaling protocols**
  - » **Diverse types of PHY processing**
- **Managing multiple deployment models and controlling costs**
  - » **Mobile users vs IoT vs low latency/high bandwidth**
  - » **Private cellular – 5G campus networks**

5G Key Technologies

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Figure based on: https://www.itu.int/en/ITU-T/gsc/Documents/GSC-20/Session-6/GSC20_Session6_5G_Chih_IEEE.ppt
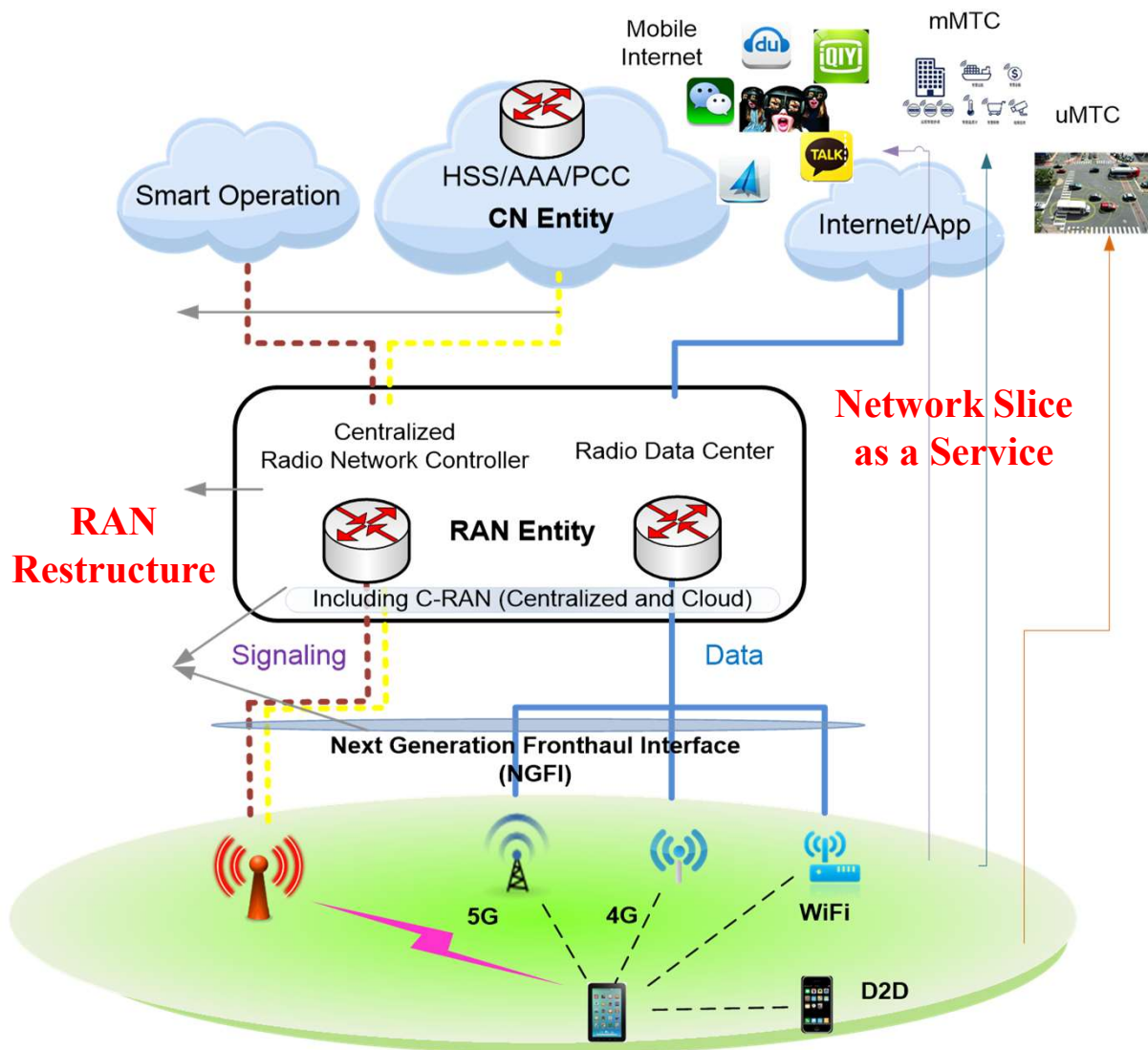
Acronyms

- **RIT: Radio Interface Technology**

- **UNC: User-centric network (data)**
  - » Optimize user (device) performance, e.g., interference mitigation

- **NGFI: Next-Generation Fronthaul Interfaces**
  - » Interface for exchanging signal information between baseband processing in C-RAN (IQ sample) and remote radio units
  - » Used in C-RAN to minimize impact of interference, …

- **SDAI: Software-Defined Air Interface (control)**
  - » Interface to manage PHY and link level: frame structure, waveform, multiple access, duplex mode, antenna configuration, ..

- **MCD: Multi-level Centralized and Distribute protocol stack:**
  - » Coordinates decision making across the system (cell, UE)

- **PTN: Packet Transport Network**

- **PON: Passive Optical Network**

Technology Discussion

- **The basestations have support for diverse front ends**
  - » Responsible for generating/transmitting baseband signal
  - » Needed to deal with diversity of frequency bands, traffic loads
- **All other processing is done in a "cloud RAN"**
  - » Responsible for both the sent/received data stream and for RAN control
- **Standard protocols to coordinate between basestations and C-RAN:**
  - » MCD stack for control of PHY and cellular protocol functions using SDIA interface
  - » UNC for RF signal data transfer based on NGFI interface

Cloud RAN (C-RAN)

- **Aggressively move processing to the cloud**
  - » **Network control, signaling protocols**
  - » **Radio signal processing**
- **Assumes moving all processing to commodity platforms instead of custom HW**
- **Use of modern cloud, networking technologies**
  - » **Virtualization, network functions (NFV), software defined networking**
  - » **Can potentially be outsourced to cloud providers**

Figure based on: https://www.itu.int/en/ITU-T/gsc/Documents/GSC-20/Session-6/GSC20_Session6_5G_Chih_IEEE.ppt

Why C-RAN?
Standard Cloud Arguments

- **Cheap compute resources**
  - » **Economy of scale of operating large data centers**
- **Elastic resource pool**
  - » **Size of the resource pool can adapt to the traffic load**
  - » **Multiplexing of resources with other users/applications**
- **Flexible allocation of resources across applications**
  - » **Relative load of different traffic classes, frequency bands**
- **Ability to outsourcing cloud management**
  - » **Can be delegated to specialized cloud providers**
  - » **Reduces infrastructure investment**
- **Virtualization offers isolation of services**

C-RAN Challenges

- **Transfer of signal data between basestations and C-RAN requires a lot of bandwidth**
  - » **Supported by the NGFI interface**

- **Processing of the signal data is latency sensitive**
  - » **Latency bounds are much tighter than for typically workloads**
  - » **Need to be able to adapt to channel conditions**
  - » **May need additional support in the cloud infrastructure**

- **RAN control needs to be driven by information obtained from signal data**
  - » **Adjust transmit powers, antennas, …**

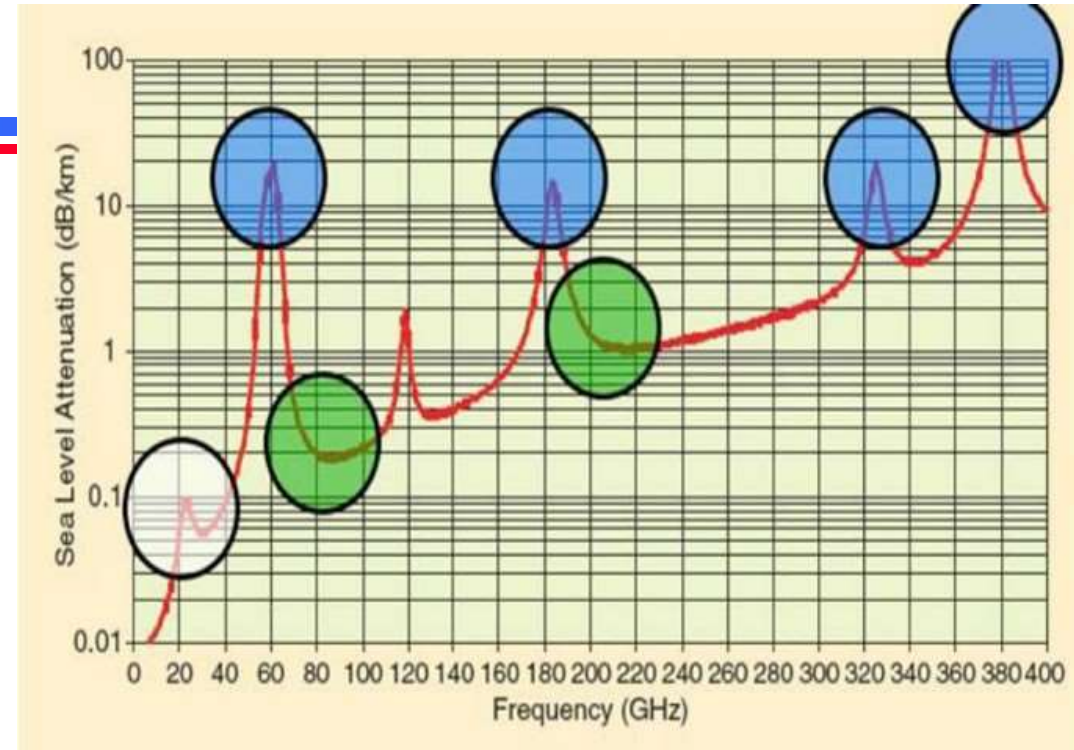Peter A. Steenkiste, CMU

Frequency Reuse

- **Frequency reuse across cells has become increasingly aggressive:**
  - » Initially, macro cells with relatively static distribution of frequencies across cells
  - » Next, introduction of micro, pico, etc. cells that are selectively deployed and can reuse frequencies more aggressively
  - » Finally, more aggressive reuse using coordinated interference mitigation across cells

- **Drive for frequency reuse is economics**

- **Goal: no cell designs, where frequencies are dynamically assigned and used "everywhere"**
  - » Very carefully limit interference during reuse
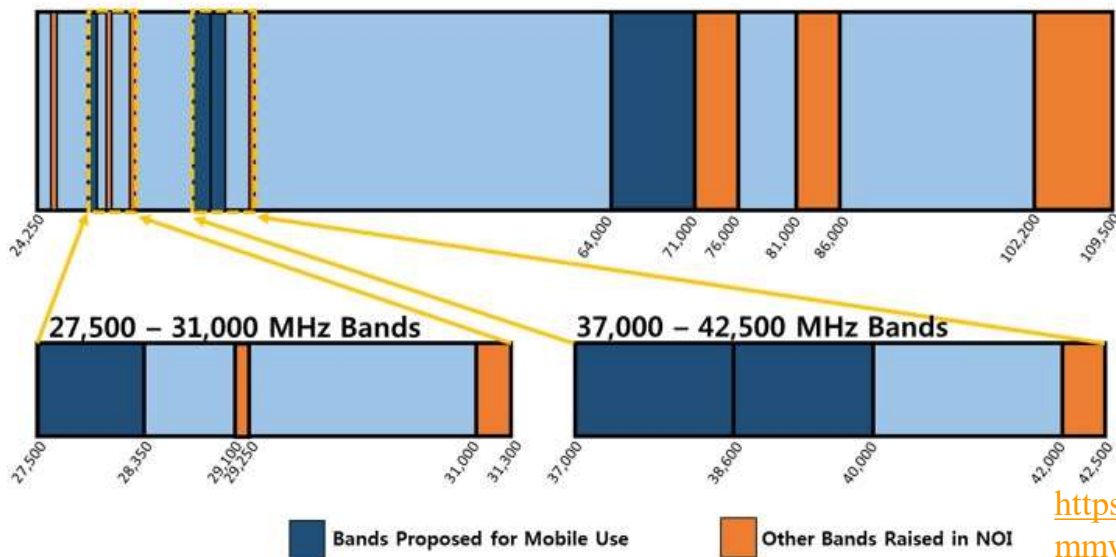
mmWave Offers Significant More Capacity

- ## There is a lot of spectrum available!
    - » See next slide for the fine print
- ## Need to use beam forming to achieve reasonable range for mmWave
    - » Possibly using large number of antennas (10s .. 100)
    - » Technology similar to that discussed for 802.11ad
    - » Challenges include establishing sessions, mobility, ..
- ## Best solution likely involves coordination between stations with "cm-wave" technologies
    - » ~GHz technologies are used for coverage
    - » mmWave is used for high capacity when needed

mmWave is Hard to Use

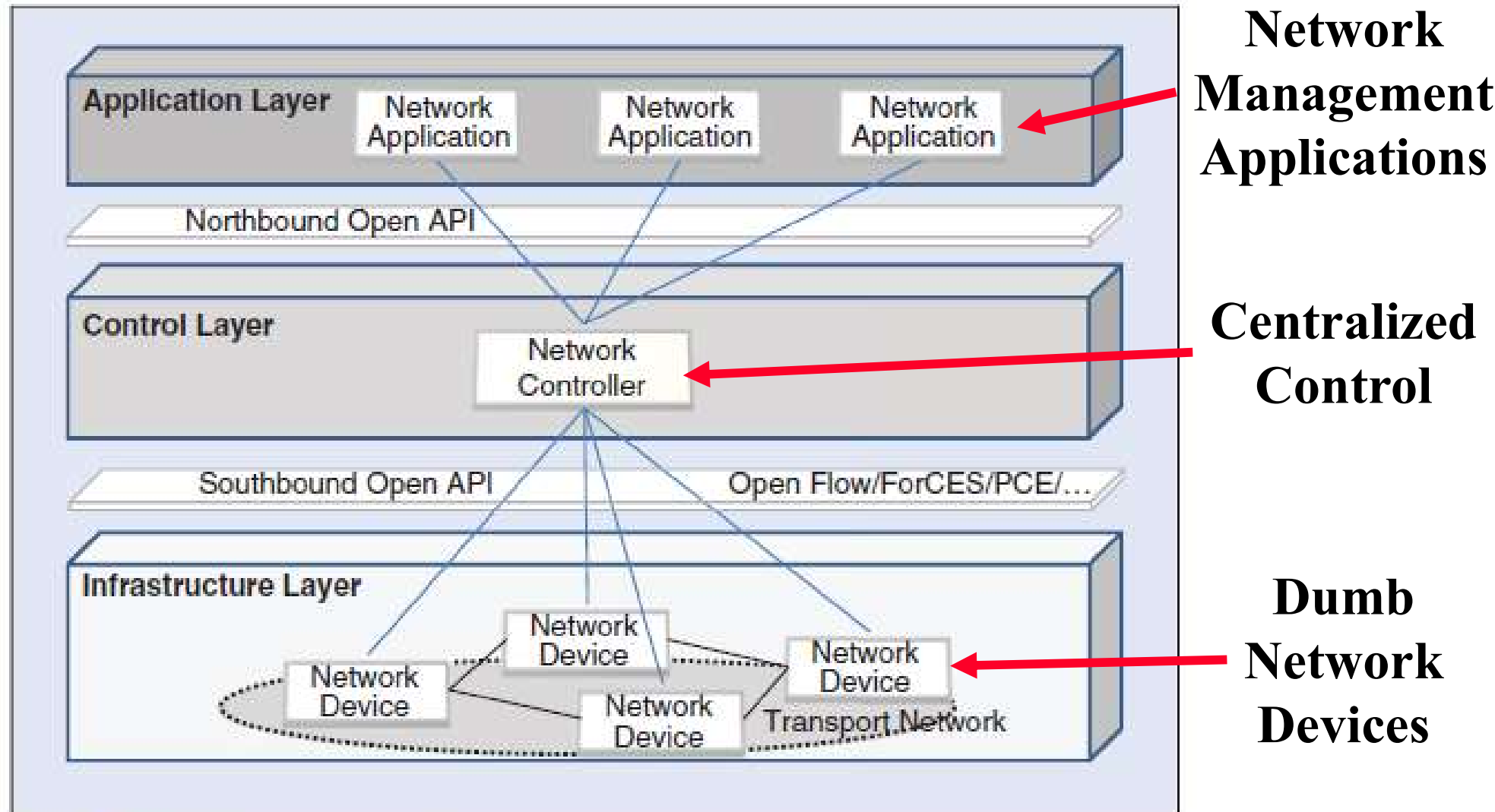- **Some mmWave frequencies are hard to use because of atmospheric absorption**
  - » **E.g., 60GHz!**

- **Cellular operators measurements studies to identify frequencies that are commercially viable**
  - » **28, 38, and 73 GHz look promising**

Bands Above 24 GHz for Possible Mobile Use

27,500 – 31,000 MHz Bands

37,000 – 42,500 MHz Bands

Bands Proposed for Mobile Use   Other Bands Raised in NOI

Use New Network Technologies in Core Network

- **Software Defined Networking (SDN)**
  - » Centralized control of the network
  - » Provides more fine grain control over resources, e.g., bandwidth management, …
- **Network Function Virtualization (NFV)**
  - » Cellular operators run a lot of "middleboxes" that provide value added services to users
  - » Traditionally supported using custom hardware but increasingly supported by "Virtual Network Functions" running on commodity servers
  - » Enabler for moving computing to clud
- **Network slicing using virtualization**
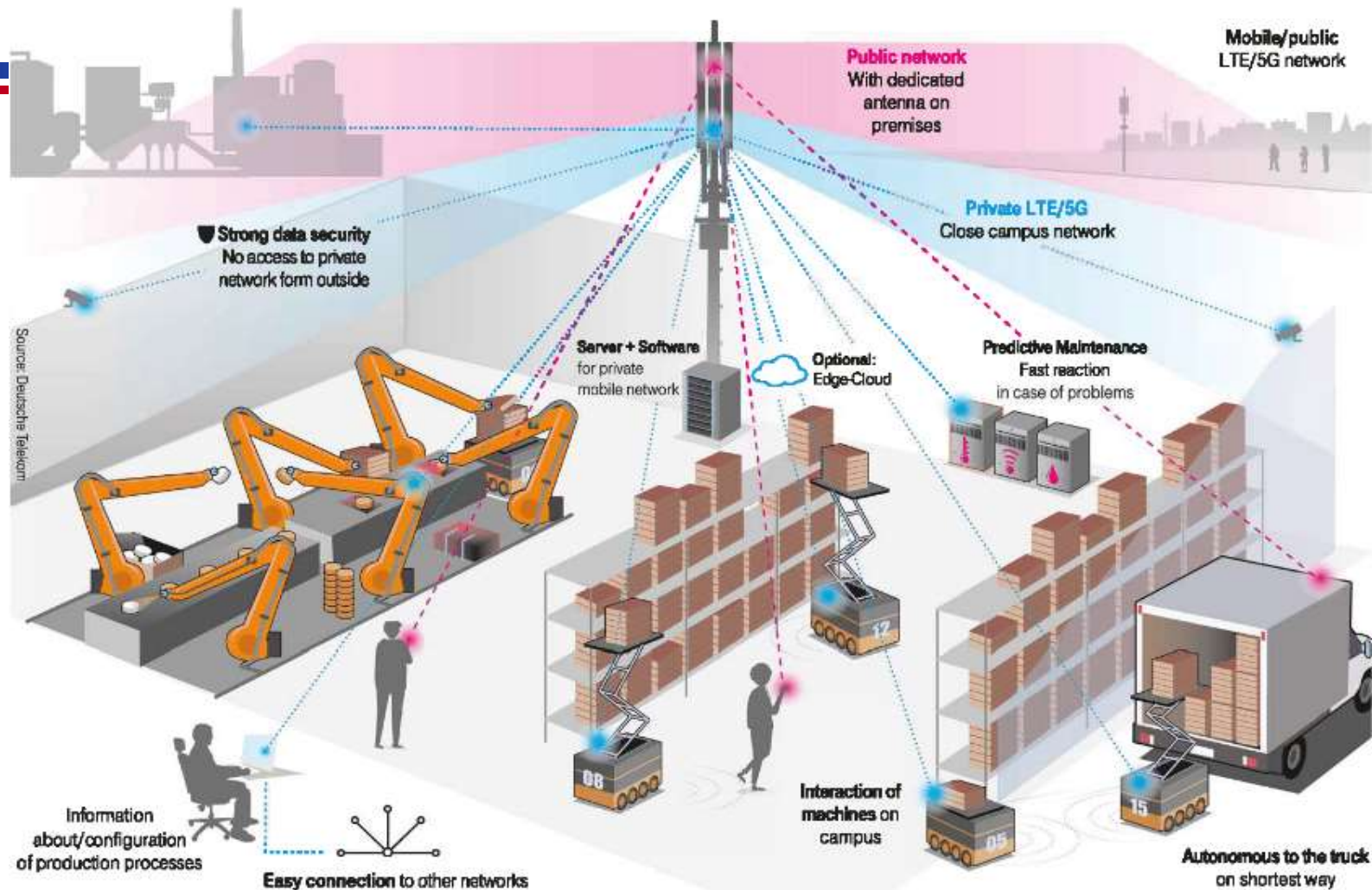 - » Flexible way of sharing a single infrastructure between several network operators and their clients

SDN concept

Network Management Applications

Centralized Control

Dumb Network Devices

P. Demestichas, "5G on the horizon: key challenges for the radio-access network." *Vehicular Technology Magazine, IEEE* (2013)
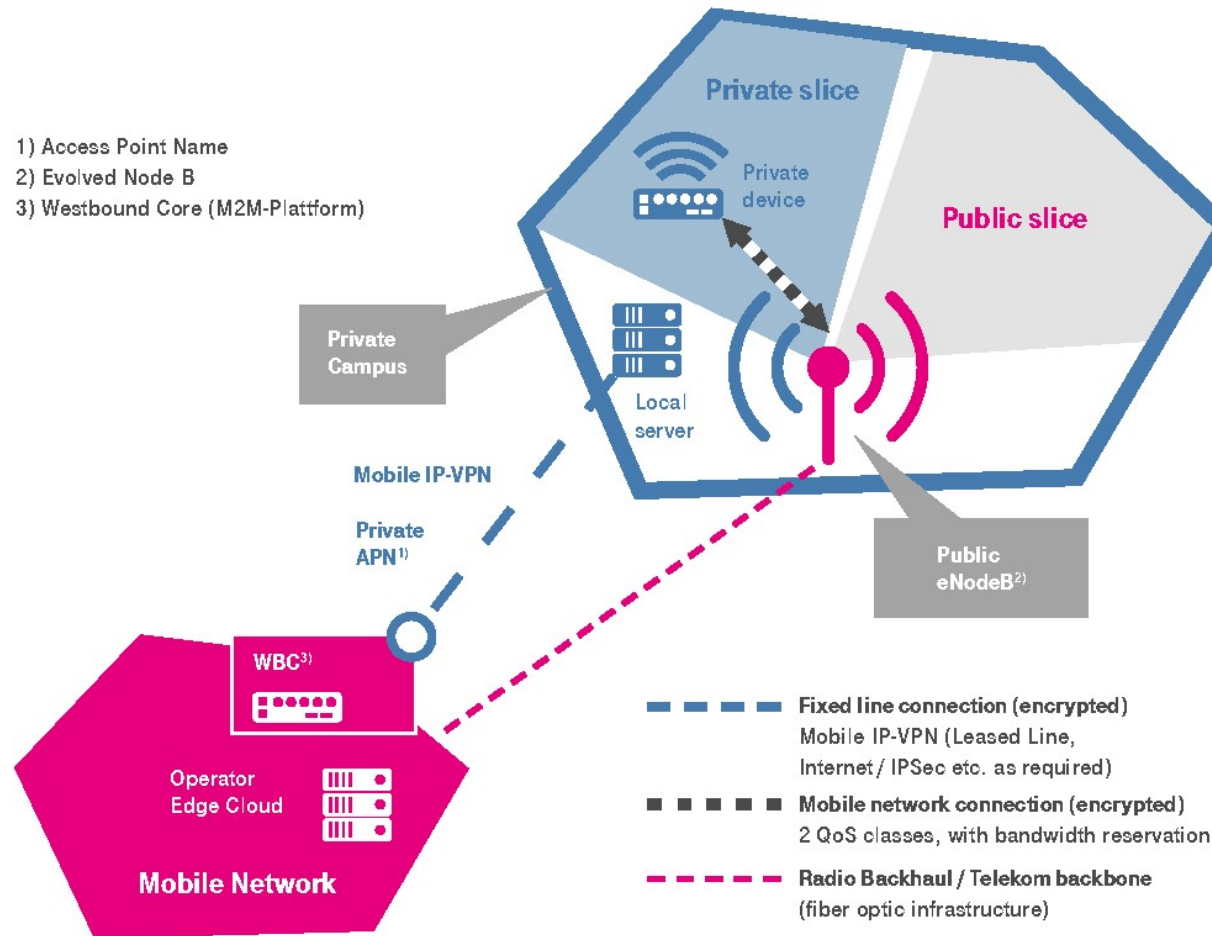
SDN Overview

- **The control plane and data forwarding plane are separated**

- **A centralized controller maintains a complete view of the network resources**

- **Network applications manage resources, control network functions**
  - » **Routing, managing QoS, traffic engineering, etc.**
  - » **Obtain network view through northbound interface**

- **Uses southbound interface to collect network state and send instructions to devices**
  - » **Protocol is called Openflow for today's IP protocols**
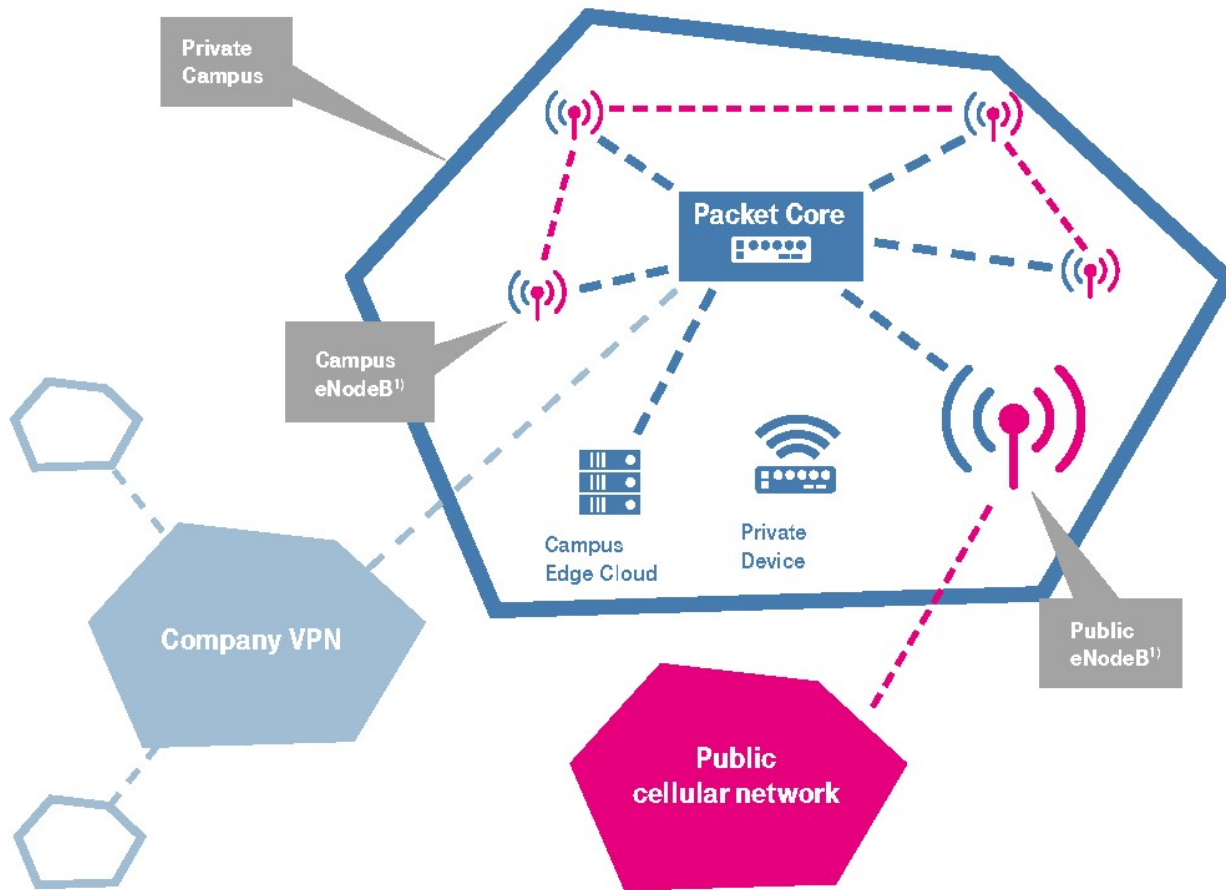
5G Campus Networks

- **Private cellular service for diverse applications**
- **Outsourcing of all wireless networking**
- **Different deployment models**

Private Campus Connectivity

- **Create a private slice with isolated resources from public networks**
  - » **Separates traffic of employees and others**
- **Can include radio infrastructure on the campus**
- **Can provide high quality of service**

Dedicated Mobile Networks

- **Can be used by both employees and others on campus**

- **Uses on site radio infrastructure**

- **Provides superior performance**